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Radio Frequency Identification Devices: Effectiveness in Improving Safeguards at Gas-Centrifuge Uranium-Enrichment Plants

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Radio Frequency Identification Devices: Effectiveness in Improving Safeguards at Gas-Centrifuge Uranium-Enrichment Plants

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ABSTRACT

Recent advances in radio frequency identification devices (RFIDs) have engendered a growing interest among international safeguards experts. Potentially, RFIDs could reduce inspection work, viz. the number of inspections, number of samples, and duration of the visits, and thus improve the efficiency and effectiveness of international safeguards. This study systematically examined the applications of RFIDs for IAEA safeguards at large gas-centrifuge enrichment plants (GCEPs). These analyses are expected to help identify the requirements and desirable properties for RFIDs, to provide insights into which vulnerabilities matter most, and help formulate the required assurance tests. This work, specifically assesses the application of RFIDs for the "Option 4" safeguards approach, proposed by Bruce Moran, U. S. Nuclear Regulatory Commission (NRC), for large gas-centrifuge uranium-enrichment plants ^[1]. The features of "Option 4" safeguards include placing RFIDs on all feed, product and tails (F/P/T) cylinders, along with RFID readers in all F/P/T stations and accountability scales. Other features of Moran's "Option 4" are Mailbox declarations, monitoring of load-cell-based weighing systems at the F/P/T stations and accountability scales, and continuous enrichment monitors. Relevant diversion paths were explored to evaluate how RFIDs improve the efficiency and effectiveness of safeguards. Additionally, the analysis addresses the use of RFIDs in conjunction with video monitoring and neutron detectors in a perimeter-monitoring approach to show that RFIDs can help to detect unidentified cylinders.

1. INTRODUCTION

The technology of Radio Frequency Identification Devices (RFIDs) recently has advanced rapidly such that various industries are adopting it to improve the efficiency of their operations, notably in tracking merchandise and managing inventory. RFIDs are systems that wirelessly transmit via radio waves the identity of and associated information about objects/merchandise to detection devices. Since RFIDs can be automatically scanned and connected to data-managing systems (computers and internet), they afford a wide variety of opportunities to track and manage objects very efficiently and quickly. One of their most visible and successful applications is in highway toll systems, such as New York State's E-ZPass.

The value of RFIDs has also been frequently mentioned in the context of helping to improve safeguards measures at advanced gas-centrifuge enrichment plants (GCEPs). For example, RFIDs could potentially help reduce the number of inspections, the number of samples collected, and the duration of visits while also improving the efficiency and effectiveness of a safeguards approach. In his study for the U.S. NRC ^[1], Bruce Moran evaluated various options to guide the selection of an IAEA safeguards approach for large GCEPs. One of his options (Option 4) included tagging cylinders with RFIDs.

This study systematically examines in detail the application of RFIDs in Moran's Option 4 and assesses their performance in improving safeguards at GCEPs. It includes a formal analysis of relevant diversion paths in such an enrichment plant. This analysis is the first step to eventually identify the requirements and desirable properties for RFIDs, provide insights into which vulnerabilities are critical, and help to formulate the assurance tests needed.

2. CURRENT SAFEGUARDS PRACTICES AT GCEPs

The following are the three principal safeguards concerns at gas-centrifuge uranium enrichment facilities declared for the production of low-enriched uranium (LEU, with <20% U-235):

1. The production and diversion of a significant quantity of uranium with enrichment greater than declared (in particular, highly enriched uranium (HEU) with $\geq 20\%$ U-235),
2. The diversion of a significant quantity of declared uranium (particularly in the form of the LEU product), and
3. The production of LEU in excess of declared amounts (e.g., using undeclared feed).

In 1980, the centrifuge-technology holders and the international inspectorates (i.e., Euratom and the IAEA) initiated the Hexapartite Safeguards Project (HSP) to agree upon an international safeguards approach for GCEPs. After 2-1/2 years of intensive study, they reached an agreement applicable to INFCIRC/153-type agreements^[2]. This approach includes inspections outside the cascade halls (primarily to detect diversion by verifying declared nuclear-material flows and inventories) and inside the cascade halls (primarily to detect the production of HEU).

The activities to be performed by the Agency and Euratom outside the cascade halls to verify the declared nuclear-material balance were based on traditional techniques, including the examination of records and reports; gross-, partial-, and bias-defect-verification measurements of relevant nuclear materials; and application of containment and surveillance techniques to maintain the continuity of knowledge. The HSP also agreed that provisions should be made to give the Agency the opportunity to verify the feed, product, and tails before they are fed to or shipped from the plant. The HSP declared that the mode of inspections would be intermittent. The HSP's conclusions have been the basis for IAEA safeguards at GCEPs since 1983.

However, the HSP did not address the possibility of undeclared feed. Therefore, the current IAEA safeguards approach at GCEPs does not include any specific measures for detecting undeclared feed or the undeclared product and tails that might be generated from it. It was not until the April 2005 meeting, "Techniques for IAEA Verification of Enrichment Activities" that the Agency considered in earnest the issue of timely detection of excess production of LEU from undeclared feed and consequent deterrence by risk of early detection. Their latest draft safeguards approach offers possible solutions to this problem. Brookhaven National Laboratory (BNL) contributed to this work by proposing the use of an enhanced "Mailbox" approach combined with video surveillance and short-notice random inspections (SNRIs). BNL's Gordon and Sanborn first introduced the Mailbox/SNRI concept in 1984 as a potential IAEA safeguards application at the Portsmouth Gas-Centrifuge Enrichment Plant^[3]

Over the last two decades, Mailbox declarations have been used to verify the receipts, production, and shipments at some bulk-handling facilities (e.g., fuel-fabrication plants)^[4]. Each day, the operator declares to the IAEA the status of the plant, including the final accountability values for feed, product, and tails cylinders using a secure Mailbox system such as a secure tamper-resistant computer. The operator also consents to hold the cylinders for an agreed period of time (called the "residence time"), after which the cylinders can be fed into the process or shipped. The IAEA verifies these declared values during short-notice random inspections using the current traditional verification methods of weighing, gamma-ray non-destructive analysis (NDA), and sampling for destructive analysis (DA).

3. MODEL PLANT AND MORAN APPROACH OPTIONS

Moran describes a model plant and safeguards options in his paper, “An Evaluation of Safeguards Approach Options for Large Gas Centrifuge Uranium Enrichment Plants”^[1]. The full capacity of the model plant is 3,000 metric tons of separative work units per year (MT SWU/yr). The plant consists of six independent cascade hall assay units, each with a capacity of 500 MT SWU/yr. The cascade halls encompass cascade enclosures within which the centrifuges are located. All six units share a Shipping and Receiving Building (SRB) and a Cylinder Accountability Area (CAA) with material-accountability scales located in the SRB for cylinders off-loaded from trucks, and also in the CAA for cylinders exiting the UF₆ Handling Areas. The model assumes that no valves or gas-sampling points are sited within the cascade enclosures but rather, are located in technical services corridors between them.

Moran considered four safeguards-approach options with various measures, each of which builds on the preceding option. His Option 4 included cylinder tagging that should, at a minimum, afford the same assurance of an item’s identification as the current markings on the UF₆ cylinders. He assumed usage of passive electronic identification tags that can be read only from within a distance of one meter; the interrogation units would be installed inside the feed and withdrawal stations. This is equivalent to using a short-range passive RFID tag.

The following safeguards features are included in Option 4:

- Operator’s Mailbox declarations of material-accounting data and operational data on the cylinder’s movements,
- Short-Notice Random Inspections to verify the specified quantities,
- Load-cell monitoring of Feed, Product, and Tails (F/P/T) Stations,
- Accountability-scale monitoring (assuming the scales have electronic outputs that the IAEA can authenticate),
- Continuous enrichment monitors (CEMO) at feed, product, and tails headers, and
- RFIDs placed on all F, P, and T cylinders with readers in all F/P/T Stations and at the accountability scales.

4. SAFEGUARDS EFFECTIVENESS OF RFIDs IN MORAN’S OPTION 4: AN EVALUATION

This study examines the diversion paths at large GCEPs and evaluates whether RFIDs improve the effectiveness and/or efficiency of IAEA safeguards in verifying the declared nuclear-material balance and in detecting the production of excess product from undeclared feed.

4.1 Assumptions

In evaluating the usefulness of RFIDs, there are many outstanding questions about their vulnerabilities, the operator’s procedures, and the capabilities of the instruments involved. Some of the assumptions made for this study are discussed below.

4.1.a Characteristics of RFIDs and Load-Cell-Based Weighing Systems

There are outstanding questions about the likelihood of defeat of RFIDs, the ability of RFIDs/readers to withstand the environmental conditions to which they will be exposed, and their

acceptability by the plant's operator. In addition, there are questions concerning the capabilities of the load-cell-based weighing systems (LCBWS):

- How well can the LCBWS measure the feed, product, and tails weights in the F/P/T stations? (i.e., how much diversion is possible within the measurement errors?)
- How well will the LCBWS hold up under operational conditions?

This study does not address these questions, but assumes that they can be answered satisfactorily. Additionally, this study assumes that the RFIDs will be short-range passive tags with a read-only number supplied by the IAEA at time of manufacture. The operator can read the read-only number and will assign a corresponding cylinder ID number to that number; this association will be declared in the Mailbox.

Since the IAEA may inspect the plant infrequently and irregularly, it is assumed that the operator applies the RFIDs to the cylinders.

- Feed cylinder: The operator applies the RFID to the full feed cylinder when it arrives at the plant.
- Customer product 30B cylinder: The operator applies the RFID to the 30B cylinder when the empty cylinder arrives at the plant.
- Interim product cylinder: The operator applies the RFID to the in-house interim product cylinders at the onset of the IAEA safeguards.
- Tails cylinder: The operator has previously applied the RFID to the incoming feed cylinder. Following Moran, this study assumes that empty feed cylinders are used as tails cylinders.

4.1.b Capability of the Continuous Enrichment Monitor (CEMO) System

Whether CEMO can be used for partial-defects test or gross-defects test of assay depends on the uncertainty of the instrument for each application. Since the precise accuracy of the uncertainty is not needed for this determination, the following assumptions were made regarding its uncertainty.

- It is assumed that the CEMO on product headers can provide a partial-defects test of assay (expected ~ 5-12% relative standard deviation (RSD)).
- It is assumed that the CEMO on feed and tails headers affords only a gross-defects test of assay (~ 25-50% RSD).

4.1.c Cylinder Handling

Six hundred and ninety (690) full feed cylinders are received, weighed, stored, and fed out each year: 625 of them are used for tails withdrawal, and 65 are returned to the feed supplier.

The Customer product 30B cylinders are received, accountability-weighed, stored, filled at the blending facility or directly from the cascades, accountability-weighed, stored, homogenized and sampled, accountability-weighed, stored, and shipped.

Some interim 48Y cylinders are used for product withdrawal and their contents are transferred to 30B cylinders at the blending facility. Interim cylinders are accountability-weighed, stored, filled, accountability-weighed, stored, some or all of their contents transferred at the blending facility, accountability-weighed, and stored. The level of enrichment of the UF₆ in these cylinders is based on estimated (process) values, not on homogenization and sampling results.

All tails cylinders are emptied 48Y feed cylinders. They are accountability-weighted, stored, filled with tails, accountability-weighted, and then stored. The level of enrichment in these tails cylinders is based on estimated (process) values, not on homogenization and sampling results.

4.2 Evaluation

Various diversion scenarios are analyzed in detail in this section to evaluate whether RFIDs improve the effectiveness and/or efficiency of IAEA safeguards in verifying the declared nuclear-material balance and in detecting the production of excess product from undeclared feed for the “Option 4” safeguards approach.

Since accountability scales and load cells at the F/P/T Stations are monitored, their readings are declared at the Mailbox, and RFIDs readers are placed at all three Stations and at the accountability scales, it is assured that undeclared feeds and withdrawals cannot be made there. However, it is unclear whether undeclared feeds and withdrawals in the Process Services Area and the UF₆ Handling Area away from the F/P/T Stations are detectable. This should be verified subsequently by Design Information Verification (DIV) and Containment and Surveillance (C/S) measures when these measures are established at an actual GCEP. Therefore, the first evaluation is based on the assumption that the DIV and C/S cannot assure the detection of undeclared feeds and withdrawals in the Process Services Area and the UF₆ Handling Area away from F/P/T Stations. The second evaluation considers the case when the DIV and C/S can assure the detection of undeclared feeds and withdrawals in the Process Services Area and the UF₆ Handling Area away from F/P/T Stations.

4.2.1 The DIV and C/S cannot assure the detection of undeclared feeds and withdrawals in the Process Services Area and the UF₆ Handling Area away from F/P/T Stations

In this section, verification of assays and weights of the feed, product and tails is examined to evaluate whether RFIDs can help in detecting diversion of UF₆ from the declared and undeclared feed for the cases where the DIV and C/S cannot assure the detection of undeclared feeds and withdrawals in the Process Services Area and the UF₆ Handling Area away from F/P/T Stations. A special diversion scenario where operator attempts to transfer an RFID from a declared cylinder to undeclared one is also examined to assess whether RFIDs can prevent this scenario.

4.2.1.a Verification of the Declared Material Balance

The operator can attempt to divert materials from the declared streams or can produce excess amounts of the product by lowering the tails assay. The excess product would be withdrawn in the two areas noted above, and the missing mass of tails would be made up by introducing natural uranium into the tails withdrawal line. Detecting the latter possibility requires, at a minimum, measurements of the tails assay. In addition, the operator can understate both the product assay and the tails assay to generate excess quantities of LEU. Consequently, the IAEA must verify the U-235 balance (i.e., the feed and product assays, as well as the tails assays.) However, there are some scenarios not detectable by RFIDs, LCBWSs, and Mailbox declarations; this case is discussed in Section 4.2.1.b, below.

- **Declared Feed Assays**

Due to the assumption that the CEMO can provide only a gross-defects test of the feed assay, IAEA inspectors must visit the plant frequently enough to perform NDA partial-defects tests and sampling/DA on feed cylinders to achieve the 50% detection probability, which is the

IAEA's target value. During these visits, relevant cylinders are declared by the operator in the Mailbox and in the Interim Inventory List (IIL) at the time of the inspection. The inspector then identifies the cylinders in the field by their cylinder numbers. The CEMO results for the feed assay are not available at this point, since it is not measured yet. Therefore, the RFID does not improve efficiency in these assay verifications.

- Declared Product Assays

It was assumed that the CEMO can provide a partial-defects test of product assay. RFIDs allow the results from the CEMO test to be associated with specific cylinders. However, to accomplish the needed sampling/DA on product cylinders, the IAEA's inspectors must visit the plant often enough to reach a 50% probability for detecting a defect. The operator declares relevant cylinders in the Mailbox and in the IIL at the time of the inspection, and the inspector identifies the cylinders in the field by their cylinder numbers. Here, RFIDs do not improve the effectiveness of the safeguards, since the inspectors still make same number of visits and inspect same number of cylinders regardless of RFIDs. However, the RFID improves the efficiency of assay verification by reducing or eliminating the need for an NDA measurement of the cylinder in the field.

- Declared Tail Assays

It was assumed that the CEMO can provide only a gross-defects test of tails assay. The use of RFIDs permits the association of gross-defect CEMO results with specific cylinders. In this case, the IAEA still must carry out NDA partial-defects tests on these cylinders, but does not need as many additional NDA measurements as in the case without RFIDs because they have the findings from the gross-defect tests (i.e. CEMO results). To do an NDA partial-defects test and sampling/DA on tails cylinders, the frequency of the IAEA's inspections must be adequate to achieve a 50% detection probability. However, since the tails cylinders reside at the facility for long periods of time, there is not an urgency to conduct more frequent inspection. The operator declares the relevant cylinders in the Mailbox and in the IIL at the time of the inspection, after which the inspector identifies the cylinders in the field by their cylinder numbers. RFIDs do not improve the effectiveness of the safeguards, since the inspectors still make same number of visits and inspect same number of cylinders regardless of RFIDs. However, the RFID improves the efficiency of assay verification by reducing the required number of field measurements of NDA partial-defects.

- Declared Weights for F/P/T

The LCBWS on the F/P/T Stations register the weights of UF_6 cylinders transferred to and from the cascade, noting the gross-full and gross-empty weights of the cylinders involved. The LCBWS values, along with the corresponding values from the accountability scales, confirm the weights entered by the operator in the Mailbox. The weights of empty tails cylinders must agree with those from the empty feed-cylinders (accountability and otherwise), since the latter are re-used and tracked by the attached RFIDs. Consequently, the IAEA need not routinely verify the weights of full and empty feed cylinders, but should randomly verify some as a check on the accountability scales and the LCBWS. The RFIDs provide the means to verify the cylinder weights that are declared in the Mailbox. This provides depth to the safeguards approach and thereby complicates any diversion strategies by the operator since all weights must be consistent. Therefore, RFIDs improve safeguards effectiveness in this case due to increased ability to verify operator statements and consequent deterrence.

4.2.1.b Scenarios not detectable by RFID, LCBWS, and Mailbox declarations - detection requires additional measures

- Diversion of Product in a 30B cylinder filled directly from the cascade

Under this diversion scenario, after receiving a declared 30B cylinder, the operator affixes the RFID to the cylinder and weighs the cylinder on the accountability scale. The operator then removes the RFID from the declared cylinder and affixes it on to an undeclared 30B cylinder whose weight has been adjusted to reasonably match the declared accountability weight. The operator then loads the undeclared cylinder into a product withdrawal (PW) station, and withdraws product into it for removal from site. The reader reads the RFID tag, the LCBWS records the weights, and the operator makes an entry in the Mailbox. After completing this operation and carefully weighing the undeclared cylinder on an undeclared scale, the operator removes the RFID tag from the undeclared cylinder and affixes it to the declared cylinder. The operator transports the declared cylinder to a concealed location, fills it with the correct weight of steel shot, moves it to the accountability scale, weighs it, and then places it in the storage yard. This cylinder is never shipped offsite. The operator could fill more product on to the steel shot, and it would not be detected by traditional NDA and DA measures. The falsification could be detected by gamma NDA and/or ultrasonic measurements through the bottom of the cylinder; but RFIDs do not aid in the detection of this diversion.

- Diversion of Product in a 48Y interim product cylinder filled from the cascade

All 48Y interim product cylinders should have an RFID permanently attached to them at the beginning of safeguards implementation. However, in this scenario, the operator claims to have acquired a new 48Y cylinder for product transfers. Given this, the operator affixes a new RFID to an undeclared 48Y cylinder and loads it into the PW station. The reader reads the RFID tag, the LCBWS records the weights, and the operator makes an entry in the Mailbox. Next, the operator withdraws some product into the undeclared cylinder for removal from the site. After carefully weighing the undeclared cylinder, the operator removes the RFID tag from the undeclared cylinder and affixes it to the newly declared cylinder. The operator fills the declared cylinder with the correct weight of steel shot at a concealed location, moves it to the accountability scale, weighs it, and then leaves it briefly in the storage yard. Later, the declared cylinder, with its RFID tag, is moved to a PW station, and UF₆ is added on to the steel shot. Then, the cylinder is transported to the accountability scale, weighed, and placed in the storage yard. The operator may never withdraw UF₆ from this cylinder, or may withdraw some material from it for blending operations. Traditional NDA and DA do not catch this falsification. Again, the deception can be detected by gamma NDA and/or ultrasonic measurements through the bottom of the cylinder, but RFIDs do not help.

- Diversion of Tails in a 48Y cylinder filled from the cascade

If an operator claims that new 48Y cylinders were purchased for tails withdrawal, then the same type of diversion strategy described above for product can be performed. However, the diversion of tails is less important for safeguards than the diversion of product.

4.2.1.c Detection of Undeclared Product Produced from Undeclared Feed

- Diversion of Undeclared F, P, and T using the declared F/P/T Stations

In this scenario, the operator introduces and removes undeclared F, P and T using the declared F/P/T Stations. RFID readers are located at every F/P/T Station. Therefore, it would be an anomaly if an undeclared cylinder with no RFID shows up in one of the F/P/T stations. This anomaly is only compounded when the LCBWS indicates the occurrence of feeding or withdrawing of material when no RFID is present. The recording of feed or withdrawals by the LCBWS without an attendant entry in the Mailbox is also an anomaly. While, the absence of an RFID confirms the anomalies observed in this scenario, it is unnecessary for its detection (i.e., the lack of a Mailbox entry suffices). Therefore, the effectiveness of safeguards is not enhanced by RFIDs in this scenario.

- Diversion of Undeclared F, P, and T using Process Services and/or UF₆ Handling Areas away from declared F/P/T Stations

In this scenario, the operator introduces and removes undeclared F, P, and T using equipment in the Process Services Area and/or the UF₆ Handling Area away from the declared F/P/T Stations. These operations most likely would be carried out with undeclared cylinders smaller than the declared 30B and 48Y cylinders. RFIDs would not be placed on the undeclared cylinders and declared cylinders with RFIDs attached would not be used for undeclared operations. Hence, RFIDs do not help in detecting feed and withdrawals at these locations.

4.2.2 The DIV and C/S can assure the detection of undeclared feeds and withdrawals in the Process Services Area and the UF₆ Handling Area away from F/P/T Stations

4.2.2.a Verification of the Declared Material Balance

The operator can attempt to divert materials from the declared streams or produce excess amounts of product by lowering the product and/or tails assays.

Excess product made by lowering the tails and/or product assays must be withdrawn somewhere along the piping. It is assumed that the DIV can assure that this removal cannot occur inside the cascade area (i.e., there are no valves or ports inside the area). It also is assumed that the DIV and C/S can assure that attempted withdrawals in the Process Services Area and the UF₆ Handling Area away from the F/P/T Stations are detected. Thus, the only remaining place where excess product could be taken is from a declared PW station. The following analysis demonstrates that this action will be detected.

Excess product can be made by lowering the tails assay; however, the amount of tails withdrawn would be too small, and equal to the weight of excess LEU produced. If the product assay also is reduced along with the tails assay, then the tails deficit is even larger. The deficit might be made up by introducing feed or tails into the piping in the Process Services Area of the UF₆ handling Area away from the F/P/T Stations. But, this evaluation assumes that the DIV and C/S can assure the detection of an attempted introduction of materials in these areas, and that, likewise, it cannot be introduced in the cascade area.. Accordingly, the tails deficit cannot be made up without detection. Hence, a uranium- or weight-balance (verified by the LCBWS) is sufficient to verify the material balance.

The LCBWS values, along with the corresponding values from the accountability scales, confirm the feed, product, and tails cylinder weights entered by the operator in the Mailbox. Therefore, the IAEA need not routinely verify the weights of full and empty cylinders. The Agency should randomly verify some of them as a check on the accountability scales and the LCBWS. The RFIDs offer a continuing association between specific cylinder weights measured by the LCBWS and the accountability scales, and the declarations in the Mailbox. Accordingly, the RFID information is redundant with the Mailbox declarations and LCBWS results, but does afford confirmatory information, thereby complicating the operator's diversion strategies, since all weights must be consistent. Thus, the RFIDs marginally improve the effectiveness of safeguards due to deterrence.

4.2.2.b Scenarios not detected by RFID, LCBWS, and Mailbox declarations - detection requires additional measures

The scenarios are the same as those described in 4.2.1.b: diversion of product in a 30B cylinder filled directly from the cascade; diversion of product in a 48Y interim product cylinder filled from the cascade; and, diversion of tails in a 48Y cylinder filled from the cascade. As in those cases, the falsification can be detected by gamma NDA and/or ultrasonic measurements through the bottom of the cylinder; RFIDs do not help in this detection.

4.2.2.c Detection of Undeclared Product Produced from Undeclared Feed

For a scenario wherein the operator introduces and removes undeclared F, P, and T using the declared F/P/T Stations, the conditions/outcomes are the same as described in 4.2.1.c, above. While the absence of an RFID on a cylinder indicates there is an anomaly, the RFID is not necessary to detect this (i.e., the lack of a Mailbox entry suffices). The use of the declared F, P, and T stations for undeclared feed and withdrawal operations is detected by the LCBWS and Mailbox results, and does not depend on the RFID. But RFIDs do provide depth to the safeguards approach and therefore would make diversion without detection more difficult and provide deterrence.

The scenario in which the operator introduces and removes undeclared F, P, and T using equipment in the Process Services Area and/or the UF₆ Handling Area away from the declared F/P/T Stations also will be detected since it is assumed that the DIV and C/S assure the detection of undeclared feeds or withdrawals made in these areas.

5. USE OF RFIDs IN THE PERIMETER MONITORING

All of the diversion scenarios at a GCEP involve introducing or handling cylinders at some point of the process. Therefore, two important steps to greatly increase the success of safeguards are (1) to identify all cylinders moving into and out of the separation buildings that house the UF₆ handling areas, process service areas, and cascade halls, and (2) to uncover the presence of unidentified cylinders.

The primary function of RFIDs in safeguards is to quickly and remotely identify cylinders that have already been tagged. However, while rapid, remote identification would be helpful for handling the cylinders (i.e., for inventory), simple identification of tagged cylinders is not sufficient for safeguards purposes. The main weakness is in the inability to notice unidentified/untagged cylinders that can be used to divert uranium. However, using RFIDs in conjunction with a video monitoring system and neutron monitoring system in the separation buildings, including their perimeters, would afford a means to better identify unknown (untagged) cylinders.

A system consisting of an RFID reader, video camera, and neutron monitor could be installed at all load-cells (feed, product, and tail), sample stations, and all functioning openings at the perimeter of the separation buildings except emergency exits. Future studies could designate the exact locations of the openings where these monitors should be installed. Operators would tag cylinders and attach seals at load cells and accountability scales in front of the monitoring cameras (procedures would be developed on how to do this effectively and with minimum interruption to the plant's operation); the readings of the load cells and accountability scales could be used as Mailbox declarations. This system would be able to detect any cylinders moving through the openings (mainly by neutron detection) both into and out of the separation buildings. If the cylinder is already tagged, the RFID reader will record the location and the cylinder identification. If it is an unidentified cylinder, it will trigger an alarm to a remote monitoring system (such as an IAEA central station) and prompt attention from inspectors. At the emergency exit doors, the system would be connected to any open-alarm trigger. Normally, these doors remain closed. However, the video monitoring system would capture any actions at the doors once the door is open and an alarm is triggered.

Once RFIDs are successfully deployed to account for all the cylinders and their movements into and out of the separation buildings, relatively simple procedures can be instituted to ensure that their contents are unaltered at any points of handling, using video monitoring and seals connected to the RFID. Any subsequent interruption/breakage of the seals also will be recorded in the RFID and monitoring video system. Nevertheless, it may still be necessary to undertake conventional inspections for NDA and DA tests to ensure the assay of contents.

Of the three concerns discussed above, the RFID would be least helpful in detecting HEU production since it mostly involves the reconfiguration and interconnection of cascades, and its detection primarily depends on visually observing the cascade area along with environmental sampling. However, HEU production also includes using some cylinders for feed and withdrawal at some points in the separation buildings. Therefore, detection of untagged cylinders at the periphery of separation buildings also will help in uncovering HEU production.

6. SUMMARY

The application of RFIDs for the "Option 4" safeguard approach proposed by Bruce Moran, U. S. NRC, at large gas-centrifuge uranium-enrichment plants was analyzed to assess RFID effectiveness and efficiency for IAEA safeguards. "Option 4" features include RFIDs placed on all feed, product, and tails cylinders along with RFID readers in all F/P/T stations and accountability scales, in addition to other features (e.g., Mailbox declarations, monitoring of load-cell-based weighing systems at the F/P/T stations and accountability scales, and CEMO). The relevant diversion paths were analyzed and the extent to which RFIDs improve efficiency and effectiveness was assessed. In general, RFIDs improve efficiency of safeguards substantially. The use of RFIDs also provides depth to the safeguards approach and complicates diversion strategy. Therefore, RFIDs slightly improve safeguards effectiveness in general due to increased ability to verify activities and consequent deterrence. This study also addresses the use of RFIDs in conjunction with video monitoring and neutron detectors in a perimeter-monitoring approach at a GCEP to show that this approach may help to detect unidentified cylinders.

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